PRELIMINARY SYSTEM DESIGN DESCRIPTION
OF THE
EBR-II FAILED-FUEL TRANSFER SYSTEM

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ABSTRACT

The failed-fuel transfer system provides additional capability to remove subassemblies, which contain failed fuel, from the primary tank in the reactor building to the argon cell of the Fuel Cycle Facility (FCF). The major parts of the system are: a dipper, with associated components; and a sealed container, with a radiation shield. The dipper retrieves the subassembly from the transfer arm and acts as a temporary storage facility by keeping the subassembly inside the primary tank without impeding standard fuel-handling operations. The dipper, containing the subassembly and sodium, can be lifted through the "X"-nozzle plug into the sealed container. The sealed container is surrounded by a radiation shield in such a manner that the combined assembly can be transferred through the equipment air lock and the reactor passageway to the basement below the FCF air cell. The radiation shield is left in the basement and the sealed container is lifted through the floor hatch of the air

cell into the air cell and from there, via the transfer lock, into the argon cell of the FCF.

1.0 INTRODUCTION

1.1 System Functions

The purpose of this system is to handle "failed-fuel subassemblies" -- subassemblies containing failed fuel -- for which the failures are too severe for normal handling (See Ref. 1, pp 34-37; and Ref. 2, pp 27-29, for descriptions of normal handling). The basic functional requirements of the system are that it:

- a. Retrieve a failed-fuel subassembly from the transfer arm;
- b. Store the subassembly in the primary tank during its cooling period;
- c. Remove the subassembly from the primary tank; and
- d. Transfer the subassembly from the reactor building to the argon cell of the Fuel Cycle Facility (FCF).

1.2 Summary Description of the System

The system enables reactor operators to transfer subassemblies containing failed fuel from the primary tank of the reactor to the Fuel Cycle Facility. The use of this system depends largely on the severity of failure. In general increasing severity of failure causes an increasing departure from standard fuel-handling procedures. The currently used fuel-handling components will be used for the transfer of failed-fuel subassemblies as long as such operations will be judged to be safe. If, however, more-severe fuel failures should occur, or be suspected to have occurred, the failed-fuel transfer system provides the means for transferring such subassemblies with minimum delay in reactor operation.

The system consists of two major parts. One is a "dipper", which is inserted through the spare nozzle ("X" nozzle) into the primary-tank sodium to retrieve the failed-fuel subassembly from the transfer arm and store the subassembly during its cooling period. The other component is a sealed container, surrounded by a radiation shield, into which the dipper and subassembly are raised after removal from the primary tank. They are transferred to the FCF, and the sealed container, without the shield, is brought into the argon cell through the air cell.

1.3 System Design Requirements

The system is based on several design, operational, and safety requirements for handling operations, from retrieval of a failed-fuel subassembly from the transfer arm to operations in the FCF. These requirements are as follows:

a. The dipper, a closed-bottom tube, must be large enough to accept a failed-fuel subassembly. The dipper diameter is limited by the internal diameter of the sealed container-shield assembly used for removal of the subassembly and transfer to the FCF.

b. Extending the dipper through the "X" nozzle to retrieve a subassembly and returning it to the transfer arm inside the primary tank must both be possible.

c. The dipper containing the subassembly might remain in storage in the primary tank for several months. During this time, the dipper must not interfere with normal fuel-handling operations, which include passing subassemblies under the "X" nozzle. While the subassembly is in storage, its decay heat must be so dissipated as to limit the fuel temperature to an acceptable value.

d. During operation of the dipper through the "X" nozzle, the seal of primary-tank blanket gas must be maintained. Any part of the "X"-nozzle modifications above the primary-tank cover must fit into the limited space available on the operating floor.

- e. The dipper filled with sodium and containing the failed-fuel subassembly must be capable of being removed from the primary tank into a shielded container.
- f. The dipper must be installed and removed in a manner that isolates the internal environment of the primary tank from the operating floor.
- g. Adequate shielding around the "X" nozzle must be provided during all transfer operations that place the subassembly above, or close to, the operating floor.
- h. During removal operations, all parts that had been in the primary-tank sodium must be maintained in an inert-gas atmosphere.
- i. Once out of the primary tank, the dipper containing a failed-fuel subassembly must be disconnected from its handling extension and must remain in the sealed container. The coupling must be designed to prevent accidental separation of the dipper from the extension, which would be highly undesirable.
- j. Materials used for fabrication of the dipper must be compatible with fuels under consideration (mixed uranium and plutonium oxides and carbides) as well as with sodium. The handling extension for the dipper and components for modification of the "X" nozzle must be compatible with sodium.
- k. The system must be designed to allow cleaning and possible decontamination of the dipper-handling extension and the components for the "X"-nozzle modification after each removal.
- l. The sealed container must be a gas-tight enclosure, large enough to accommodate a dipper. The largest diameter of the dipper or its handling extension must be small enough for the dipper and extension to pass through the sealed container. The container must center the dipper device.

m. The sealed container and radiation shield must weigh less than 20 tons and be handled readily by the building crane. The radiation shield and the sealed container must pass through the equipment air lock and the reactor passageway on the cask-transfer carts. Therefore, the size of the container and shield is limited by the space above the primary tank, by the internal space of the equipment air lock, and by the space available below the FCF air-cell floor hatch.

n. The sealed container must be separable from the radiation shield to permit transfer of the container to the air cell via the air-cell floor hatch.

o. During removal of a failed-fuel subassembly from the primary tank and during transfer to the FCF, the sealed container must remain within the radiation shield.

p. During removal operations, the fit between the sealed container and the "X"-nozzle modification must be gas-tight.

q. The cooling system for the sealed container must: (1) be able to remove at least 0.70 kW of subassembly decay heat; and (2) be independent of the radiation shield.

r. The sealed container must be small enough to pass through the large transfer lock between the air and argon cells.

s. During transfer operations, the sealed container must have an inert-gas atmosphere.

t. The shield must provide adequate radiation shielding during all transfer operations.

u. Materials and components used in the fabrication of the sealed container must withstand radiation levels normally encountered close to fully irradiated subassemblies.

v. For the sealed container, ease of disassembly and access to components is required to allow routine servicing and decontamination.

w. All operations in the FCF associated with the sealed container must have the capability of being performed remotely from outside the air cell and argon cell by using available manipulators and cranes. A relatively simple removal of the dipper (containing the failed-fuel subassembly) from the sealed container must be possible.

2.0 DETAILED DESCRIPTION OF SYSTEM

2.1 Dipper and "X"-Nozzle Modification

2.1.1 Dipper

The dipper (Fig. 1) is a closed-bottom tube about 4-1/2 in. in diameter and almost as long as a fuel subassembly (87 in.). To enhance radiant heat transfer (increase emissivity) during subsequent handling operations, the dipper is black-chrome plated. This process leaves a thin surface layer (0.00005-0.000075 in.) of chromium oxide. The plating is compatible with sodium at the temperatures under consideration. Tests have indicated that 0.38 g of oxygen would be released to the bulk sodium from a dipper with this plating.

While in the primary tank, the dipper is coupled to a long handling extension, the top of which is accessible from the reactor operating floor. The assembly is installed in a special plug within the spare nozzle ("X" nozzle). This plug connects to an extension tube with a packing gland on top, through which the system can be raised, lowered, and rotated.

Below the packing gland is a 6-in. gate valve used to seal off the primary-tank atmosphere when the dipper and handling extension are removed.

The dipper is coupled to the handling extension by a two-bayonet type of coupling. The coupling joint is designed to allow sodium to drain from it. Contact between the dipper and handling extension is made on two 1/4-in.-wide strips at the top and bottom of the

Fig. 1. Failed-fuel Transfer System (Dipper Positions)

coupling. The bayonet coupling is prevented from uncoupling by a locking lug between the handling extension and the dipper. This lug is retracted by a cam within the sealed container, i.e., uncoupling can only occur after the dipper is removed from the primary tank.

The dipper and handling extension are separated by upward motion of the coupling past cams inside the sealed container. The sequence is as follows: the handling extension becomes confined between two vertical slots in the sealed container, the locking lug is lifted by a cam, and finally the bayonet lugs on the dipper come in contact with two inclined planes that rotate the dipper out of the bayonet slots in the extension. The extension can then be removed, leaving the dipper suspended from two protrusions in the container wall.

The first function of the dipper is to retrieve the failed-fuel subassembly from the transfer arm. When a subassembly is being transferred by the transfer-arm mechanism from the storage basket to the transfer port, the subassembly passes directly below the "X" nozzle. This nozzle, about 10 in. in diameter, is directly above the fuel-subassembly catch basin. The subassembly is retrieved by first swinging it to between the "X" nozzle and fuel-transfer port. Next, the dipper is lowered until its mouth (open end) is 1 in. below the level of the lowest part of the hanging subassembly. The transfer arm is rotated until the subassembly is directly over the mouth of the dipper (a in Fig. 1). The dipper then is raised until it contains the subassembly. The subassembly is held at the desired angle inside the dipper by a hexagonal ring. If a wiggle test assures that the subassembly is within the dipper, the transfer arm is disengaged and pulled away.

The dipper and subassembly can now be lifted and held at various elevations in the primary tank. When raised 93 in., the bottom of the dipper is about 3-1/2 in. above the transfer arm. With the dipper in this position (c, Fig. 1) standard fuel handling can proceed without interference from the dipper. The dipper remains full of sodium, and decay heat is transferred to the primary-tank sodium.

2.1.2 "X"-nozzle Modification

The "X"-nozzle modification consists of a new "X"-nozzle shield plug, extension tube, gate valve, and packing gland. The shield

plug, which is inserted into the "X" nozzle, extends a sleeve into the primary-tank sodium. The plug provides a 5-1/2 in. opening for the dipper and handling extension. The shield plug is supported by eight jack screws, which provide the vertical adjustment needed to align the "X"-nozzle opening with the axis of the subassembly. After alignment is attained, a ring seal in the plug flange is torqued down, making a gas-tight seal with the existing "X"-nozzle flange. Because the plug sleeve dips into the primary-tank sodium and the ring seal seals the plug at the "X"-nozzle flange, no blanket gas can escape after installation of the plug. Bearings at the top and bottom of the shield plug center the dipper handling extension at different operational positions.

The 80-in. extension tube, containing a 6-in. gate valve, is bolted to the top of the "X"-nozzle plug. This places the valve about 42 in. above the operating floor. Bolted to the gate valve is the packing gland, through which the dipper and handling extension are actuated. Using the extension tube on top of the "X"-nozzle plug assures that all of the components of the dipper and handling extension that previously were exposed to sodium remain below the packing-gland elevation within the inert atmosphere of the "X"-nozzle plug. The gate valve remains open throughout all operations of the dipper in the primary tank. Upon final removal of the dipper the valve is closed, thus sealing access to the primary tank.

After installation and adjustment of the "X"-nozzle plug, a layer of temporary gamma shielding (lead bricks) is placed around the "X"-nozzle extension. This shielding protects operators from radiation that may result when the dipper is raised to allow for fuel handling or when the subassembly is being removed from the primary tank. To limit upward streaming of radiation from the failed subassembly, the lower end of the dipper extension is fabricated from a solid steel bar.

During operation the dipper is moved vertically by using a tower structure and a winch operated from the operating floor level (b in Fig. 1). The building crane is used for installation and removal. The dipper, handling extension, and failed-fuel subassembly weigh about 850 lb.

2.2 Sealed Container and Radiation Shield

The failed-fuel subassembly is removed from the primary tank and transferred to the FCF with the sealed container and radiation-shield assembly (Fig. 2).

The sealed container is a gas-tight tubular component about 9 ft. long and 5-1/2-in. ID. At its lower end is a plug valve large enough to pass a 5-1/2-in. tube. At the top is a 6-in. gate valve. The sealed container can be inserted readily into and removed from its mating radiation shield. The radiation shield, a tube of lead about 9 ft. long with a 9-in.-thick wall and a 12-in. ID, weighs about 15 tons.

While in the sealed container, the subassembly can generate as much as 0.7 kW of decay heat (which was established as a design criteria). Heat is transferred from the fuel elements within the subassembly to the wall of the dipper by conductance through the sodium that remains in the dipper with the subassembly. In the initial design, the sealed container has longitudinal fins to increase the surface area exposed when the container operates in the air and argon cells without the radiation shield. Heat-transfer calculations indicate that at maximum heat generation the dipper temperature would drop to about 325°F when the sealed container is not enclosed and to 425°F when the sealed container is within the radiation shield. Heat transfer from the dipper to the wall of the sealed container is assumed to be by radiation only.

A second type of sealed container, with a liquid-argon cooling jacket instead of fins, will be evaluated for possible future use. It will permit the dipper sodium to be frozen around the failed subassembly during transfer.

During removal, the sealed container remains within the radiation shield. The container and shield are supported by a special structure, which in turn is supported by a primary-tank T1 support beam and the center circular support beam.

In preparation for removing the dipper and subassembly from the primary tank, the "X" nozzle is purged with fresh argon, and the nozzle packing gland is removed. Next, the sealed container and radiation shield are brought into place above the "X" nozzle. The bottom of the

Fig. 2. Failed-fuel Transfer System (Placement of Sealed Container and Radiation Shield)

sealed container slips into an adapter on the nozzle gate valve, making a gas-tight seal with the nozzle. The handling extension protrudes through the sealed container and through a packing gland above the container. At this time, the space within the "X" nozzle and the sealed container is again isolated from that of the operating-floor area.

The dipper is raised out of the primary tank by using the building crane. First, it is lifted high enough to permit the "X"-nozzle gate valve and the sealed-container bottom plug valve to be closed. Further lifting uncouples the dipper from the handling extension. The uncoupling cam and inclined planes (see p. 16) are on the inside diameter of the sealed container. The handling extension is then lifted out of the sealed container and the container's top gate valve is closed. The packing gland above the container is removed, and a shielding plate is fastened above the gate valve. The subassembly is now ready to be transferred to the FCF.

3.0 PRINCIPLES OF OPERATION

3.1 Utilization

The fuel-handling components now used operate satisfactorily and may continue to be used for the transfer of failed-fuel subassemblies. If, however, more severe failures should occur, or be suspected, the proposed system will provide the means for transferring such subassemblies with the minimum delay in reactor operations.

Several categories of failures, arranged in increasing severity have been described. Determining the extent of some failures while a subassembly is in the primary tank will be difficult, but the categories may help in determining the removal method from the deduced or suspected extent of damage.

The proposed fuel-transfer system probably would be used predominantly for "intermediate" failures. An "intermediate" failure has been described as a subassembly containing ruptured fuel elements, in which surfaces of irradiated fuel are exposed and in which there may have been extensive melting through the cladding wall. By definition

"intermediate" failures might seriously contaminate the fuel-unloading machine (FUM). Also, the failed-fuel subassembly might be swollen or bowed enough to prevent its being placed into the storage basket.

3.2 Installation

To minimize reactor downtime, the dipper should be installed in the primary tank before a failure occurs. Installation of the dipper and "X"-nozzle shield plug probably would require only a short time and could be done during a routine reactor shutdown. Adjusting the "X"-nozzle shield plug and aligning the dipper would require several days but could be done during reactor operation.

The dipper is installed in three steps. First, the "X"-nozzle shield plug is installed in the nozzle by standard techniques (either bagging or argon purging). Next, the "X"-nozzle extension with the gate valve attached is bolted to the nozzle shield plug. Finally, the dipper and handling-extension assembly, with the packing gland in position, are lowered through the open gate valve into the primary tank. The packing gland is bolted directly to the gate valve. After these steps, the primary-tank seal is again established and reactor operation can resume.

Adjusting the "X"-nozzle shield plug and vertically aligning the dipper are necessary because the nozzle is believed to be slightly tilted, owing to bowing of the primary-tank cover. The tilt of the shield plug is compensated for by adjusting the plug jack screws that bear on the "X"-nozzle flange.

Vertical alignment and final adjustment of the dipper are checked by using a dummy subassembly suspended from the transfer arm. Several subassembly retrievals are made. These initial alignment tests also include transfer-arm disengagement and reengagement and removal of the subassembly from the dipper by using the transfer arm. These tests are performed at bulk-sodium temperature of 700°F. When the desired alignment is attained, the "X"-nozzle shield plug is locked in place, and a set of reference-level bubbles on the plug are zeroed. In this manner the plug can be returned to the correct positions should misalignment reoccur. The dipper device is also locked in the proper angular orientation, and the exact transfer-arm angle that corresponds to the "X"-nozzle position is referenced for future use.

Because the "X"-nozzle shield plug is not removed during removal of the failed-fuel subassembly, the above adjustments should be necessary only during initial installation of the system. Insertion of a new dipper (the dipper extension is reused) will not affect the adjustments.

3.3 Operation in the Primary Tank

For all the handling operations performed in the primary tank, the dipper and its extension remain in a fixed angular orientation with respect to the tank. The orientation is such that if the dipper is at its lowest (retrieval) elevation and the transfer arm is rotated from the transfer port toward the storage basket, the arm will come into contact with a stop on the dipper extension. In this position, if a subassembly were hanging from the transfer arm its vertical axis would be in line with that of the dipper, and the lowest part of the subassembly would be 1.765 in. above the dipper mouth.

A subassembly is retrieved from the transfer arm by moving the dipper vertically from the operating floor with a hand-operated winch. Holes at the proper elevations in the handling extension accept holding pins that support and accurately position the dipper below.

Although the dipper may be held at any elevation in the primary tank, only four basic positions are contemplated:

a. Retrieval Position -- In this position the dipper mouth is 1.765 in. below the lowest point of a subassembly hanging from the transfer arm. This position occurs during initial insertion and removal (if required) of a failed-fuel subassembly from the dipper (a in Fig. 1).

b. Transfer-arm Position -- In this position the mouth of the dipper is about 2 in. below the transfer-arm elevation, and subassembly support has been transferred from the transfer arm to the dipper. In this position the subassembly is engaged and disengaged from the transfer arm. If segregation of the dipper sodium from the primary-tank sodium were not required, the transfer-arm position could be used for storage. This position must be vacated during standard handling of fuel between the storage basket and the transfer port.

c. Storage Position I -- In this position, (b in Fig. 1) the mouth of the dipper is about 2 in. above the primary-tank sodium level (at 700°F), and within the "X"-nozzle shield plug. At this elevation, there is no communication between the dipper sodium and the primary-tank sodium or blanket gas. Because most of the dipper remains submerged in the primary-tank sodium, the subassembly will be stored in this position during its cooling period. Again, this position must be temporarily vacated during normal transfer of fuel subassemblies from the storage basket to the transfer port.

d. Storage Position II -- In this position (c in Fig. 1), the lower 50 in. of the dipper remains submerged in the primary-tank sodium, and the top part of the dipper is in the "X"-nozzle shield plug. Whenever transfer of a subassembly from the storage basket to the transfer port (or vice versa) is required, the dipper must be raised to this position to clear the transfer-arm path. In storage position II, there is a clearance of 3-1/2 in. between the lowest part of the dipper and the horizontal center line of the transfer arm. For subassemblies generating zero or low power, this position can be used for indefinite storage; thus the dipper need not be lifted during standard fuel handling.

The choice of storage positions and residence time will depend largely on characteristics of a failed subassembly -- e.g., burnup, power generation, and extent of failure.

3.4 Removal and Transfer Operations

Subassemblies will be removed from the primary tank during a routine reactor shutdown. The removal is accomplished by raising the dipper containing the failed subassembly out of the primary tank and into a bottom-loading container (sealed container). During removal and transfer to FCF, the subassembly remains submerged in the sodium within the dipper. Because of the good conductivity of the sodium (50 Btu/hr-ft-°F), decay heat is readily transferred from the subassembly to the surface (about 8 ft²) of the dipper. The failed-fuel subassembly remains in the dipper, which stays within the sealed container during all transfer operations from the reactor building to the argon cell.

Transfer of the sealed container and radiation shield from the reactor building to the FCF follows the same route normally taken by the interbuilding coffin³. The unit is lifted by the building crane and placed into the equipment air lock. The lock contains a cart that carries the sealed container and radiation shield along rails from one end of the lock to the other. The radiation shield is so fitted that the standard carts can be used for all transfer operations. The shield and container then are lifted by a 20-ton hoist and placed on the coffin-transfer car in the reactor passageway. The car is driven along rails in the passageway that joins the reactor building to the FCF. The shield and container are lifted by a 20-ton crane and lowered onto a similar cart in the basement of the building. This cart is driven into the area beneath the air cell.

The shield and container are then positioned under the air-cell floor hatch, and the container is disconnected from the shield. The 36-in. shielding plug in the floor of the air cell is removed, and a crane is used to lift the sealed container into the cell. (The sealed container with dipper and subassembly weighs about 1000 lb.) The radiation shield remains behind.

Next, the sealed container is placed in the large transfer lock and transferred from the air cell to the argon cell. During its stay in the air cell, the container remains closed, thus sealing its contents from the air atmosphere. In the argon cell, the container's top gate valve can be opened and the dipper and subassembly removed. For a failed-fuel subassembly generating zero or low power, the sodium within the dipper will be frozen; therefore the dipper must be placed in a heater to extract the subassembly.

Disposal of the dipper and its sodium (about 35 lb) is required, but the sealed container can be decontaminated and reused.

4.0 SAFETY PRECAUTIONS

The chief safety precautions cover the five situations listed below.

4.1 Damage to the Reactor during Installation and Operation of the Dipper Device

During insertion into the primary tank, the dipper is not expected to come into contact with any reactor components. However, as a precaution, a dynamometer is placed between the dipper and the lowering device to indicate interference.

During operation, the only primary-tank component to interact with the dipper device is the transfer arm. The interaction is similar to that of the transfer arm and storage basket except that, with the dipper device, there is more "feel" because its operation, like that of the transfer arm, is manual. Interlocks between the dipper's vertical position and the transfer arm's angular orientation are not anticipated because the consequences of the transfer arm hitting the dipper are thought to be insignificant.

4.2 Radiation Hazard during Dipper Operation

In storage positions I and II, the irradiated failed-fuel subassembly is higher than normal in the primary tank. Therefore, additional shielding on the primary-tank cover probably will be required. The amount and location of this shielding is being investigated.

4.3 Radiation Hazard during Removal and Transfer of the Subassembly from the Primary Tank

During removal operations, the irradiated subassembly is brought out of the primary tank and into the sealed container. Temporary shielding must be placed both above and below the container. The amount and location of this shielding is being investigated.

Calculations have indicated that the lead radiation shield surrounding the sealed container should be 9 in. thick to limit surface dose to 75 mr/hr (the calculation assumes a line source 13.5 in. long and heat generation of 700 W).

4.4 Containment of the Subassembly during Transfer to FCF

During transfer to the argon cell of the FCF, the subassembly remains in the closed-bottom dipper, which is full of sodium (depending on heat generation, the sodium may be molten or solid). The dipper is held within the sealed container in an inert-gas atmosphere. Both the top and bottom container valves are sealed with O-rings. During removal and transfer to FCF, the sealed container is bolted to the 15-ton radiation shield.

4.5 Loss of Cooling Capability during Transfer

The ability to transfer heat from the subassembly to the dipper wall requires that the dipper be full of sodium. The procedures will require the sealed container to be kept vertical at all times. However, should the sealed container be dropped on its side or inadvertently placed in a horizontal position, much of the sodium would run out of the dipper and lodge in the annulus between the dipper and the sealed container. Subsequently, when the container is placed upright, the dipper would be only partially full of sodium. In the worst condition, no sodium would remain in the core region and the fuel would begin to heat. Assuming the subassembly was generating 700 W, an estimated 30 to 40 minutes would be available to transfer the sealed container into the argon cell of the FCF, where the subassembly could be removed and gas-cooled by the time the temperature would reach 1200°F. If more than 30 to 40 minutes were needed to complete the transfer, the temperature would increase to more than the arbitrary limit of 1200°F. Even such a drastic situation would not endanger the personnel or the reactor because the sealed container would still be adequate to hold the hot fuel; the failed subassembly possibly could be adversely affected in regard to meeting its experimental objectives.

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